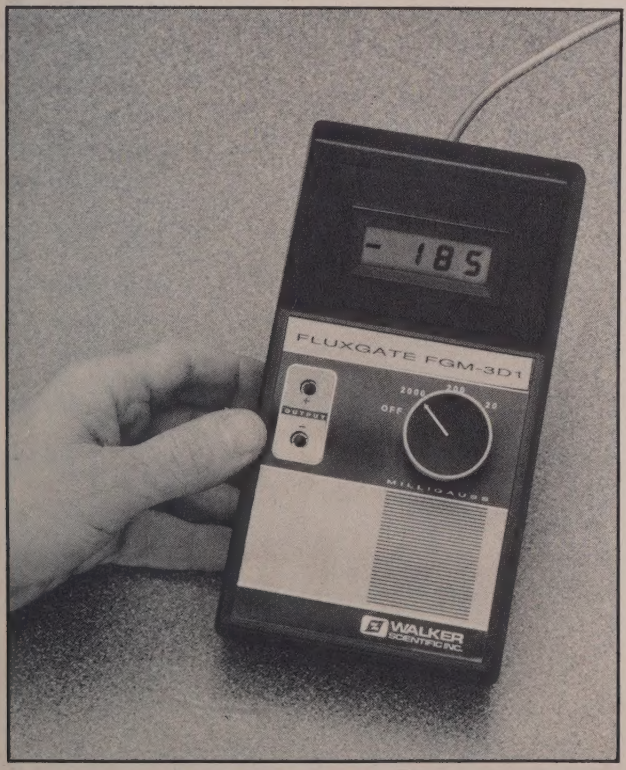
WALKER SCIENTIFIC INC.

FGM-3D1 Instruction Manual



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GENERAL

The FGM-3D1 is a sophisticated and highly accurate instrument, yet it is simple and easy to use. There are no adjustments to make. Just turn the range knob from OFF to the range of interest and the field measurement appears on the 3½ digit display. The measurements are accurate to ±0.5% of full scale over the 0° C to 50° C operating temperature range. No temperature compensation is required.

A low impedance output is provided which can be used to connect the FGM-3D1 to strip chart recorders or data acquisition systems. This output maintains the same accuracy and stability as the digital display.

The FGM-3D1 is powered by a conventional 9 Volt alkaline battery which provides approximately 35 hours of continuous service. A zinc/air battery can be used to achieve a 60 hour operating life. The FGM-3D1 may also be powered by a 9 Volt battery eliminator which may be purchased from WSI or many other sources. See the section on BATTERY ELIMINATOR for its specification. The next section describes how to operate the FGM-3D1. This is followed by some general information on maintenance. The section on Applications briefly describes how the FGM-3D1 can be used to solve some typical measurement problems. The final two sections give the FGM-3D1 specifications and the analog output calibration data for this unit.

OPERATIONS

The FGM-3D1 is turned on by rotating the Range Selection switch clockwise from the OFF position to any of the ranges. The switch should be returned to this position after being used in order to preserve battery life.

Range Selection

The range is selected by aligning the vertical bar of the Range Selection switch with the number which represents the full-scale range in milligauss. This action also causes the Analog Output full-scale range to correspondingly change and the decimal point on the meter to adjust so that the meter reads in milli-gauss.

Probe Orientation

The displayed measurement represents the vector component of the magnetic field directed along the long axis of the probe. An arrow on the probe indicates this direction. The short perpendicular line across the center of the arrow indicates the middle of the probe. A positive reading indicates the field is directed from the cable end of the probe to the free end. In other words, the same direction as the arrow.

Analog Output

The FGM-3D1 analog output provides a low impedance buffered version of the signal going to the LCD panel meter. A dual banana plug is used to connect the FGM-3D1 to external devices. This output can be short-circuited without damaging the FGM-3D1 or disturbing the displayed measurement.

The output voltage range is ± 2 Volts which corresponds to the full-scale range selected by the range switch. The output voltage can be as great as ± 4 Volts. Accuracy is not guaranteed for outputs beyond ± 2 Volts.

Battery Low Indicator

When the battery voltage drops below 5.1 Volts, the left most decimal point turns on indicating that the battery is low and should be replaced. The FGM-3D1 will continue to operate but the indicated field value may not be reliable.

Battery Eliminator

The FGM-3D1 may be powered by a 9 Volt battery eliminator which may be purchased from WSI. The battery eliminator is connected to the FGM-3D1 through a standard barrel connector on the lower right side of the case. The battery does not need to be removed.

MAINTENANCE

The FGM-3D1 requires very little maintenance. There are no operator adjustments required. The electronics unit is housed in a shock resistant plastic case. This case is not watertight and should not be immersed in water. The LCD display may be cleaned using a damp cloth.

The sensor probe may be immersed in water. It is encapsulated and the sensor cable is watertight.

Battery Replacement

The battery is contained in a compartment located on the lower backside of the electronics unit case. A sliding hatch door provides access. The FGM-3D1 was designed to be powered by a conventional 9 Volt alkaline battery such as an Eveready No. 522. Other kinds of 9 Volt batteries may also be used. A list of some of these alternate batteries is given below:

Duracell	MN1604	Alkaline
Eveready	E146X	Mercuric Oxide
Duracell	DA146	Zinc/Air

The alkaline and mercuric oxide batteries will provide approximately 35 hours of continuous operation. The zinc/air battery will provide a continuous operation time of about 60 hours.

Fuse Replacement

A fuse inside the FGM-3D1 electronics unit protects it from damage caused by the application of reverse battery voltage or a part failure which could cause excess current to flow. In the very rare circumstance where the fuse needs to be replaced, the operator may do so by removing the four screws on the corners of the case. These are accessible from the back. The replacement fuse should be a Littlefuse Type F, 212.315, 315 mA 250 Volts or equivalent.

APPLICATIONS

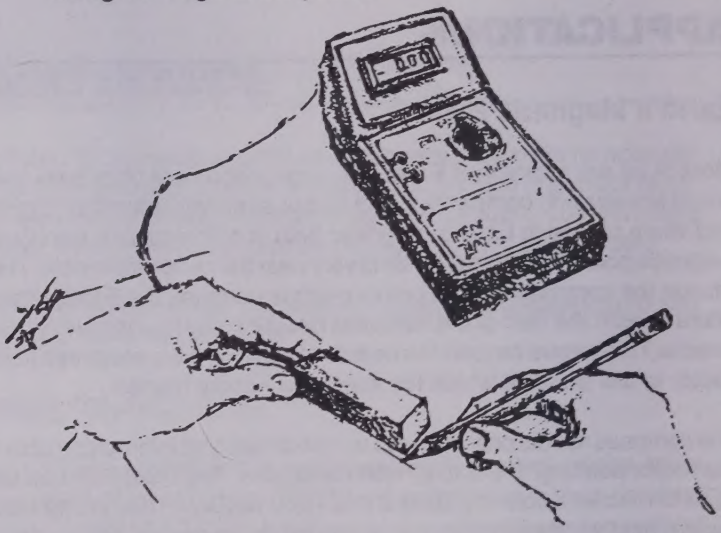
Earth's Magnetic Field

Most of us are aware that Earth has a magnetic field of its own. We are all familiar with compasses. The compass needle is itself a magnet and when placed in Earth's magnetic field, it points toward the north magnetic pole which coincidently is very near the geographic pole. The reason the compass needle points north is because the Earth's field interacts with the field of the compass needle causing a torque on the needle. This torque causes the needle to align with the magnetic field vector in the plane in which the compass needle rotates.

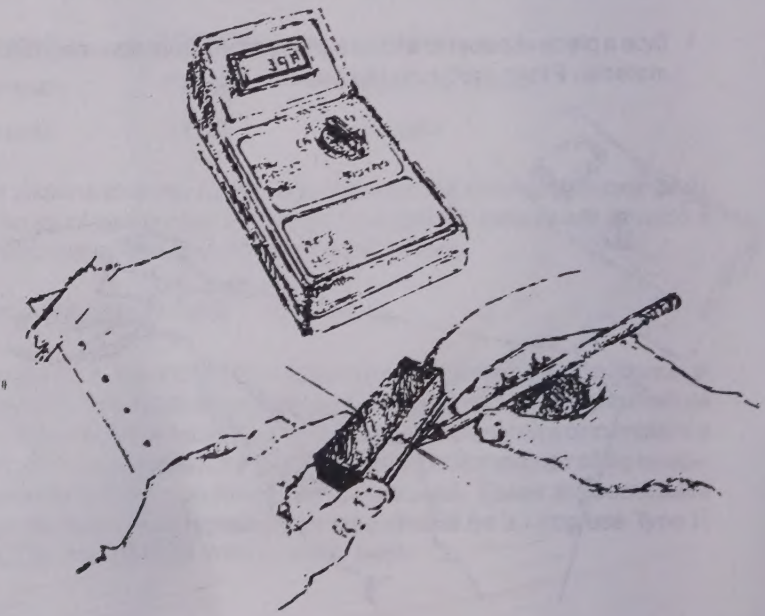
The compass needle only provides us with directional information about the vector pointing to the magnetic north pole. The FGM-3D1 can be used to measure both the DIRECTION and MAGNITUDE of the total Earth's field vector as well as its north-south, east-west, and vertical vector components. Follow the steps illustrated below. Make sure you are outside and at least ten feet away from any magnetic object (anything made from iron or steel).

1. Tape a piece of paper to a level surface made from non-magnetic material. Place probe on the paper.

2. Rotate probe for zero reading. Draw a straight line on the paper along the edge of the probe.



3. Draw a line at right angles to the first line. Align the probe edge along this line and record the FGM-3D1 output. This is the horizontal component (H) of Earth's field.



4. Orient the probe in the vertical direction with the end flat against the surface where the two lines cross. Record the FGM-3D1 output. This is the vertical component (V) of Earth's field.

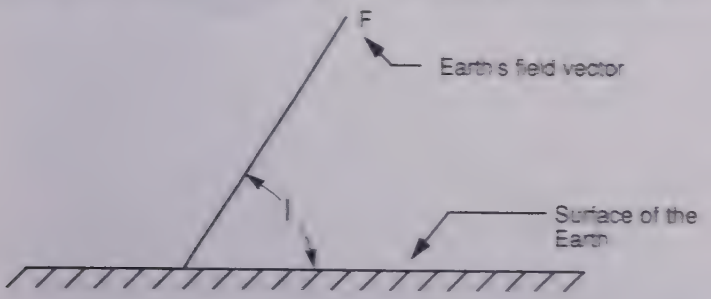
5. Compute the total field magnitude.

   Total Field (F) = $\sqrt{H^2 + V^2}$

6. Compute the inclination of the field.

   Inclination (I) = arctan $\frac{V}{H}$

The first line drawn on the paper is the East-West direction. The second line is the North-South direction. The inclination angle is the angle between the Earth's magnetic field vector and the horizontal plane.



A positive reading when measuring H indicates the direction of the north magnetic pole.

The 1988 values for I, H, V, F, and D (magnetic declination) in several U.S. cities are listed in Table 1.0. This data was determined by using a computer model available from the U. S. Department of Commerce. The magnetic declination can be used to determine Geodetic North. If the sign is positive then the Geodetic North is west of the magnetic north. If it is negative then it is east of the magnetic north.

TABLE 1.0 MAGNETIC DATA FOR SOME U.S. CITIES

CITY	H(nT)	V(nT)	F(nT)	I(deg)	D(deg)
WASHINGTON, D.C.	20,535	49,866	53,929	67.62	– 13.48
NEW YORK, N.Y.	19,508	51,553	55,121	69.27	– 12.83
MIAMI, FL	25,721	39,768	47,360	57.11	– 3.34
CHICAGO, IL	18,643	53,922	57,054	70.93	– 1.28
DENVER, CO	21,509	50,636	55,015	66.99	11.24
SAN FRANCISCO, CA	25,094	36,658	44,424	55.61	– 15.72
LOS ANGELES, CA	25,283	42,260	49,246	59.11	14.03
SAN DIEGO, CA	25,674	41,413	48,726	58.20	13.50
SEATTLE, WA	19,208	52,742	56,131	69.99	20.25
NEW ORLEANS, LA	24,797	43,902	50,421	60.54	2.45
BOSTON, MA	18,881	52,003	55,324	70.04	– 15.84

H – Horizontal Component
V – Vertical Component
F – Total Field Magnitude
I – Inclination
D – Declination

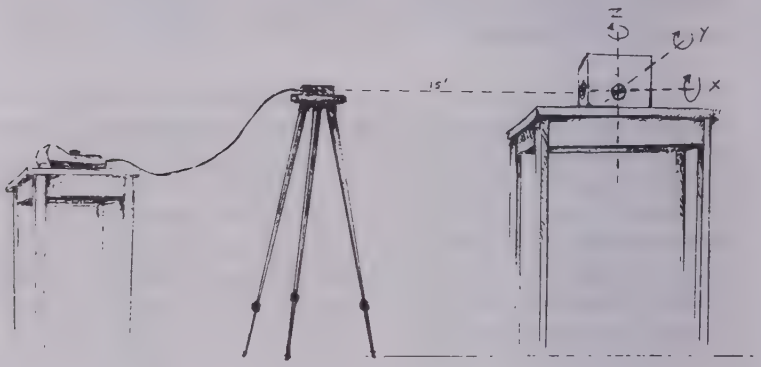
Package Inspection

The U. S. Federal Aviation Administration (FAA) requires that a package which contains magnetic material must be inspected to make sure that its influence on the local field will not affect magnetic navigational equipment. The FGM-3D1 can be used to perform this inspection. Its 1nT (gamma) sensitivity and ±0.5% accuracy are more than adequate to meet the FAA requirement.

The specification requires that the package produce a change in the magnetic field of less than 525nT at a distance of 15 feet from its geometric center. When performing this test, it is important that the sensor and package be well away from objects which are made of magnetic material and can interact with the magnetic field of the package. Objects which are made of iron or steel should be at least ten feet away from the closest point of the sensor or package. Reinforcing rods in the cement floors of a building can cause problems. Keep the package at least 3 feet above the floor.

The person performing the test should remove any objects such as belt buckles, watch, or keys which can cause an error in the reading. Also no objects other than the package under test should be moved during the test. The test site should be at least 50 feet away from a roadway or parking lot where automobiles might be driving by.

The testing method is illustrated below:



1. Place the FGM-3D1 probe in a horizontal position on a non-magnetic structure at approximately the same height above the floor as the geometric center of the package. The line joining the probe and package should be approximately east-west.

2. With the package removed, rotate the probe in the horizontal plane until the FGM-3D1 reads zero ± 10nT. Record the meter reading.

3. Place the package under test at a horizontal distance of 15 feet from the probe and in line with the arrow on top of the probe. The geometric center of the package should be at the same height as the probe. The line joining the probe and package should be at right angles to one side of the package.

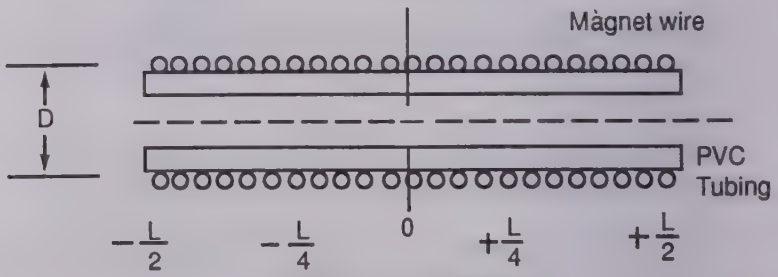
4. Slowly rotate the package one revolution about the X axis while observing the FGM-3D1 display. Note the maximum FGM-3D1 reading.

5. Repeat step 4 for the Y and Z axes. If any maximum reading exceeds ±525nT, the package has failed inspection.

6. Remove the package and record the FGM-3D1 reading. If the difference between this and the step 2 reading is greater than 10nT, then repeat the test.

Calibrating Solenoids

A solenoid is one of the simplest and easiest ways to generate a uniform magnetic field. It can be constructed using tubing made from non-magnetic material, such as PVC which can be purchased from a plumbing supply store. The field inside the solenoid is uniform over a large volume.



Field is uniform within
1% in this volume.

The field at the very center of the solenoid directed along its length is

$$H = \frac{0.4\pi NI}{L\sqrt{1+(D/L)^2}} \text{ Gauss}$$

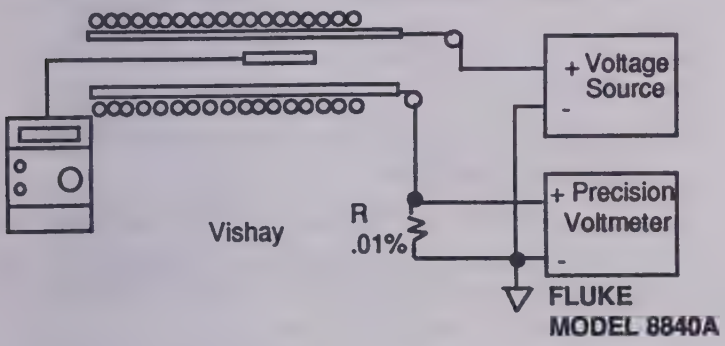
where I = the current in the solenoid (Amperes)

N = the number of turns

L = the length of the solenoid (cm)

D = the diameter of the winding (cm)

The magnitude of the field depends on the number of turns per cm (N/L), the current, and the ratio of coil diameter to length (D/L). The turns per cm are determined by the wire diameter, if closely packed, or by the spacing between turns. Long thin solenoids are very insensitive to changes in coil diameter.



The solenoid can be calibrated using the FGM-3D1, a precision voltmeter, a voltage source, and a precision resistor. The resistor should have a sufficient power rating and temperature coefficient so that its value will not change more than .01% when passing the calibration current. The voltage source must be very stable during the calibration period. A bench top power supply is not usually good enough. The voltage should not change more than 1 part in 10,000 over the period of calibration.

If these conditions are met, the calibration procedure described below should yield a coil constant (milligauss per milliampere) which is accurate to better than 1%.

The solenoid should be at least three feet away from any ferromagnetic objects, otherwise their presence may influence the field inside the solenoid.

1. Place the FGM-3D1 probe at the geometric center of the solenoid with the arrow on the probe parallel to the long axis of the solenoid.

2. Rotate the solenoid and probe until the FGM-3D1 reads less than ±10nT. Put the FGM-3D1 on the 2000 mGauss range.

3. Adjust the voltage source until the FGM-3D1 reads 1000 milligauss. Record the voltmeter reading.

4. Reverse the solenoid leads so that the current is flowing in the opposite direction.

5. Adjust the voltage source until the voltmeter reads the same value recorded in step 3.

6. The FGM-3D1 should indicate about 1000 milligauss but with a polarity which is opposite to that observed in step 3. Add the magnitude of the step 3 and step 6 FGM-3D1 readings and divide by 2.

$$H = \text{Applied Field} = \frac{\text{step 3 reading} + \text{step 6 reading}}{2}$$

7. Divide the voltmeter reading by the resistance R to compute the current which produced the field.

$$I = \frac{1000x\ (\text{Voltmeter Reading})}{R} \quad \text{(milliamperes)}$$

8. Compute the solenoid coil constant.

$$K = \frac{H}{I} \left(\frac{\text{milligauss}}{\text{milliamperes}} \right)$$

9. Disconnect the voltage source and read the FGM-3D1. If the reading is greater than 1 milligauss then repeat the calibration procedure.

Measuring AC Fields with the FGM-3D1

Although the FGM-3D1 is normally used to measure the DC component of magnetic fields, the AC component of the field can also be measured using the analog output feature. The digital display shows only the value of the DC component of the magnetic field. On the other hand, the analog output has a frequency response which extends from DC to 100 Hz (2000 and 200 milligauss range) and through appropriate processing can be used to measure AC fields, such as those generated by commercial power lines, household appliances, and electrically powered machines.

Care must be taken in measuring the AC field. Since the FGM-3D1 measures both the DC and AC components, the sum of both fields must not exceed the full scale range of the FGM-3D1. The following equation must be satisfied:

$$(\text{DC field}) + (\text{rms AC field}) \times \sqrt{2} < \text{full scale range}.$$

The earth is immersed in a uniform DC magnetic field which ranges in magnitude from 400 to 750 milligauss and varies in direction from being horizontal in the equatorial zones to near vertical in the temperate zones. The FGM-3D1 probe can sometimes be oriented so that it is at right angles to the Earth's field, thus reducing the DC field component and allowing more AC field measurement range or increased sensitivity. In many cases, the AC field source may be oriented in such a way that the Earth's DC field component is significant. In this case, the AC field measurement range will be reduced. If a DC magnetic field source such as a magnet is available, it can be used to null or reduce the net DC field seen by the FGM-3D1. The magnet can be brought near the probe. Then by rotating and adjusting the distance between the magnet and probe, the DC component can be reduced to a lower level, thereby increasing the AC field measuring range. The AC field measured by the FGM-3D1 may be influenced by the presence of the magnet.

The simplest arrangement for measuring AC magnetic fields is to connect the analog output of the FGM-3D1 to the input of a multimeter. The multimeter should be set initially to the Volts AC func-

tion and the 200 millivolt range. the FGM-3D1 should be set on the 2000 milligauss range. The voltage displayed on the multimeter will then read directly in units which correspond to the range of the FGM-3D1 (1 millivolt = 1milligauss). On a 3 1/2 digit multimeter, the resolution will be 0.1 milligauss rms.

The multimeter will display the rms value of the AC field measured by the FGM-3D1. The FGM-3D1 probe can be slowly moved around to locate and measure the AC field. As the probe is moved, there will be a transient value displayed on the multimeter which dies away after a few seconds when the probe is held steady. The probe must be held steady for several seconds in order to get an accurate reading. The operator should be monitoring both the FGM-3D1 and the multimeter display to make sure the above equation is satisfied.

The above settings for the FGM-3D1 and multimeter will provide an AC field measurement resolution of 0.1 milligauss with a maximum AC field range of 200 milligauss which should be adequate for most applications. If greater AC field range is required, the multimeter can be placed on the 2 volt range. This will increase the maximum AC field measurement range to 1400 milligauss. The voltmeter reading will now be directly in Gauss rms (1 volt = 1 Gauss). If lower level fields are to be measured, the FGM-3D1 may be operated on the 200 milligauss range with the multimeter on the 200 millivolt range. The operator must pay close attention to the DC field level to make sure that the FGM-3D1 is not in saturation and that the above equation is satisfied. In this configuration, a 10 millivolt reading on the multimeter corresponds to a 1 milligauss rms AC field.

The simple arrangement discussed above does not discriminate between different AC field signals. All AC fields, which are in the DC to 100 Hz bandwidth of the FGM-3D1, will be included in the rms value displayed on the multimeter.* Commercial power related fields are the most common AC fields found in the urban environment. Even in rural areas, the power line fields dominate all other signals in the D to 100Hz bandwidth. More than likely, the AC field measured in the simple arrangement above is the fundamental

** The multimeter AC volts specification will establish lowest frequency AC field which can be measured.*

component of the commercial power generated field (60Hz in North America, 50Hz in Europe). If discrimination between signals is desired then the user must place a frequency discrimination circuit between the FGM-3D1 output and the multimeter.

A simple band pass filter that just allows the AC component of interest to pass through will handle the problem. The filter should have a gain of one at its center frequency and should heavily attenuate signals at frequencies above and below the center frequency. Such a circuit is illustrated in the accompanying figure.

The circuit component values are given by the following equations:

$$R_2 = \frac{Q}{\pi f_r C}$$

$$R_{1a} = \frac{R}{2} 2$$

$$R_{1b} = \frac{R_2/2}{2Q^2-1}$$

$$BW = \frac{f}{Q} r$$

At the resonant frequency (f) the gain is 1. Typical component values for a 60 Hz power one filter with a bandwidth of 6 Hz are:

R_2 = 536.000 KΩ

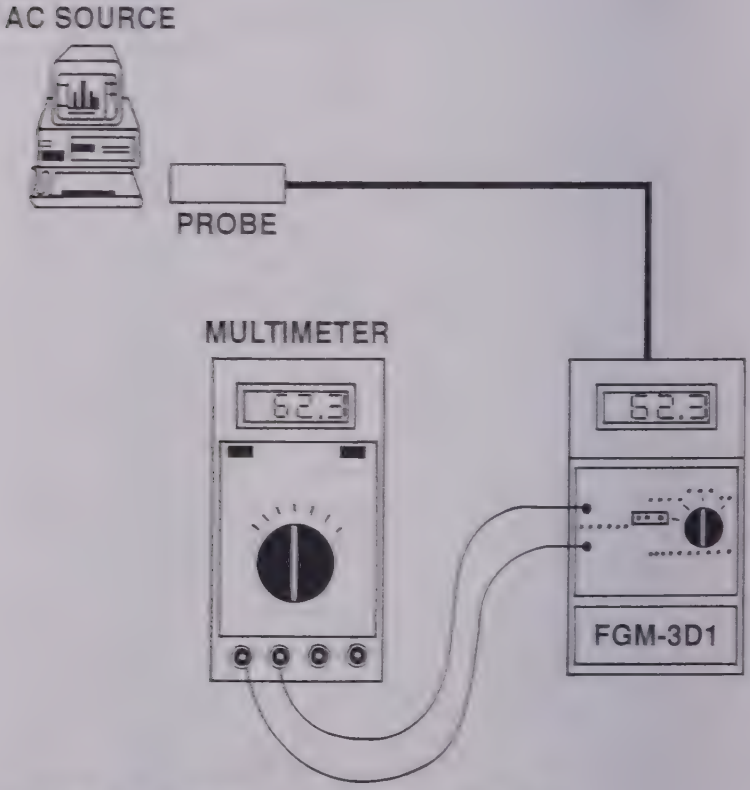
R_{1a} = 267.000 KΩ

R_{1b} = 1.347 KΩ

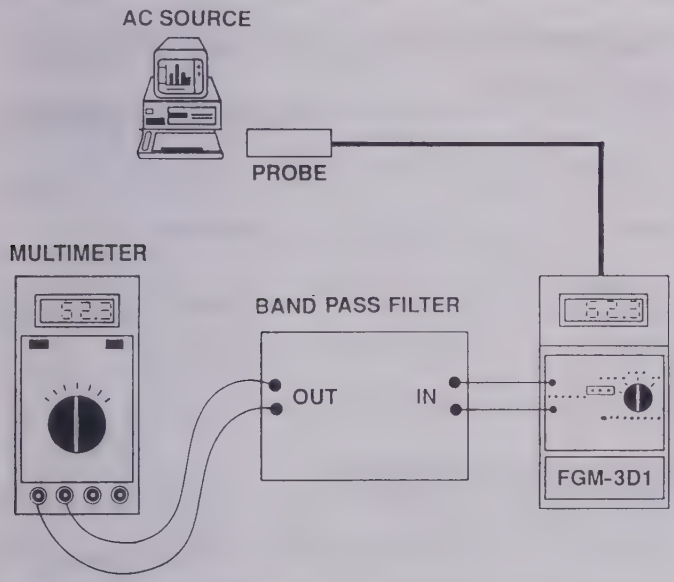
C = 0.100 uF

The resonant frequency is adjusted by changing R_{1b}. The output of the filter can be applied to the input of a multimeter. Alternatively, the output can be applied to an RMS to DC converter and then either to a multimeter set to the DC VOLTS function or to the input of a strip chart recorder or data acquisition system if the user wants to record the field amplitude over time.

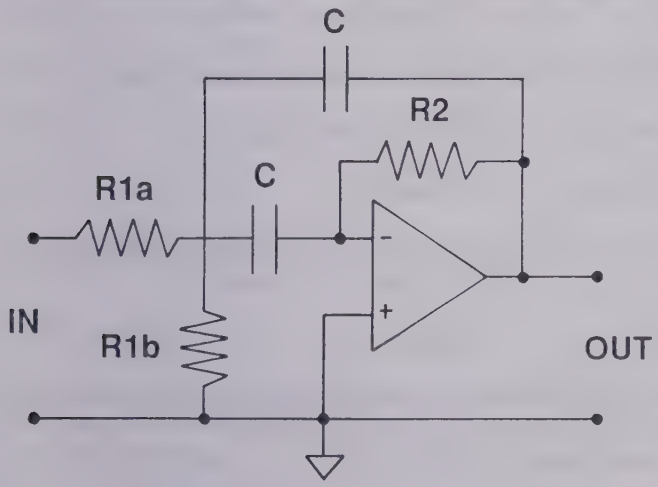
In conclusion, the FGM-3D1 is not only an instrument for measuring DC magnetic fields but it can also be used to measure low frequency AC magnetic fields, such as those generated by power lines, household appliances, power tools, transformers, and electrically powered machinery.



SIMPLE METHOD FOR MEASURING AC FIELDS WITH A FGM-3D1



MORE SIGNAL DISCRIMINATION CAN BE ACHIEVED WITH A BAND PASS FILTER



BAND PASS FILTER FOR DISCRIMINATING AC MAGNETIC FIELDS

MAGNETIC FIELD CONVERSION FACTORS

1 gamma (γ) = 1 nanotesla (nT)

1 tesla = 10^4 gauss = 1 weber/meter^2

1 ampere/meter = $4\pi x10^{-2}$ oersted

1 weber = 1 volt-second

1 gauss/oersted = $4\pi x10^{-7}$ henry/meter

SPECIFICATIONS

Ranges	: ±2000, ±200.0, ±20.00 milligauss FS
Resolution	: 1 part in 2000 (1nT on 20 mG range)
Accuracy	: ±0.5% of FS ±1 count
Power Consumption	: 150 milliwatts maximum at 9 Volts
Power Source	: 9 Volt Alkaline Battery
Analog Output	: ±2 Volts
Frequency Response	: 100 Hz on 2000 and 200 mG ranges 50 Hz on 20 mG range
Linearity	: ±0.02% of FS
Weight	: 15 oz. (.425 Kg) including Sensor
Temperature Range	: 0 to 50° C
Display	: 3½ digit LCD

CALIBRATION DATA

SERIAL NO.: 1852 DATE: 1/15/92

FIELD	ANALOG OUTPUT (VOLTS) 2000mG	200.0mG	20.00mG
1.0 FS	1.9975	1.9981	1.9962
.75 FS	1.4986	1.4991	1.4971
.50 FS	0.9990	0.9993	0.9973
.25 FS	0.4992	0.4993	0.4971
0	-0.0006	-0.0007	-0.0029
−.25 FS	-0.5004	-0.5008	-0.5028
−.50 FS	-1.0003	-1.0006	-1.0031
−.75 FS	-1.5000	-1.5004	-1.5029
−1.0 FS	-1.9987	-1.9995	-2.0018
SCALE FACTOR (mV/mG)	9.995589e-4	9.998896e-3	1.000023e-1

FS = full scale range

This is to certify that the FGM-3D1 with the above serial number has been calibrated and tested to meet or exceed the published specifications for this instrument.

Certified Steve Colbourn Date 1/15/93

Quality Control Engineer

WARRANTY

Except as otherwise expressly stated herein, company makes no warranty of any kind whatever, express or implied, with respect to the goods sold or to be sold hereunder and all implied warranties of merchantability and fitness for a particular purpose are hereby disclaimed by the company and excluded from this agreement and sale. Purchaser agrees that there are no, and will be no understandings, agreements or representations, expressed or implied, not specified herein regarding this order or sale. Purchaser further agrees that in the event of a breach of any warranty by the company, the liability of the company shall be expressly limited to the remedies set forth herein and the company shall not be liable for any other damages, direct or indirect, including lost profits or incidental or consequential damages of any kind.

The company agrees that, for a period of one year from the date of sale thereof, the goods shall be free from defects in material and workmanship and agrees to replace, FOB the company's factory, any part or parts malfunctioning within such one year period, excluding fuses and batteries, provided the purchaser has given immediate notice of such malfunction and such malfunction, in the opinion of the company, shows inmistakable evidence of, and is solely due to, defective material or workmanship. The liability of the company shall not in any case exceed the cost of repairing or replacing defective parts. At the end of said one-year period, all liability of the company shall cease and terminate. In connection with any repair performned by the company pursuant to this provision, the company shall have the right to make such changes in design and construction as it deems advisable for the purpose of improving the goods or meeting any special condition. The company makes no warranties with respect to goods or services of other manufacturers or servicers and disclaims all liability therefor.

The warranties and remedies set forth in this paragraph are exclusive of all other warranties and remedies; they are not alternative warranties and remedies.

If fault has been caused by misuse or abnormal conditions of operation, repairs will be billed at a nominal cost. If so requested, an estimate will be submitted before work is started.

Walker Scientific, Inc., must be notified and permission must be granted before equipment can be returned to our factory for repair.

If any fault develops, the following steps should be taken: Notify Walker Scientific, Inc., giving full details of the difficulty and include the model number, instrument type and serial number. Upon receipt of this information, service instructions or shipping instructions will be given. If the equipment is to be returned for service, please package it carefully to reduce the possiblity of additional damage.

Shipping Damage: If the equipment is damaged in transit, the purchaser must first contact the carrier to report the damage. The carrier will send out an inspector to inspect the damage and the inspector will fill out the damage report. The purchaser must not estimate the cost of damage. The purchaser must forward one (1) copy of this report to Walker Scientific, Inc. Our Service Department will contact the purchaser to make the necessary arrangements for the return of the equipment for a thorough inspection. Walker Scientific, Inc. will contact the purchaser with an itemized cost to either repair or replace the defective components or equipment. The purchaser should then contact the carrier to make the necessary arrangements for payment. Walker Scientific Inc. will bill the purchaser, providing the equipment was shipped FOB our plant for all repairs. The purchaser will have to collect the cost of damages directly from the carrier.

NOTES

NOTES

Quality Assurance Product Group
Rockdale Street, Worcester, Massachusetts
01606 U.S.A.
Telex: 910250817 Telephone: (508) 852-3674
Fax: (508) 856-9931
Code name: "Walker Sci"

MP MASTER
MA35532